MERIDIONAL MOISTURE TRANSPORT BY EXTRA-TROPICAL CYCLONES IN THE SOUTHERN HEMISPHERE

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MOTIVATION

- Precipitation is strongly related to moisture flux convergence
- Heavy precipitation can lead to floods
- Changes to climatological moisture fluxes will alter precipitation patterns
- Vital to know how precipitation will change in the future
- In models precipitation is parameterized whereas v and q are often prognostic variables

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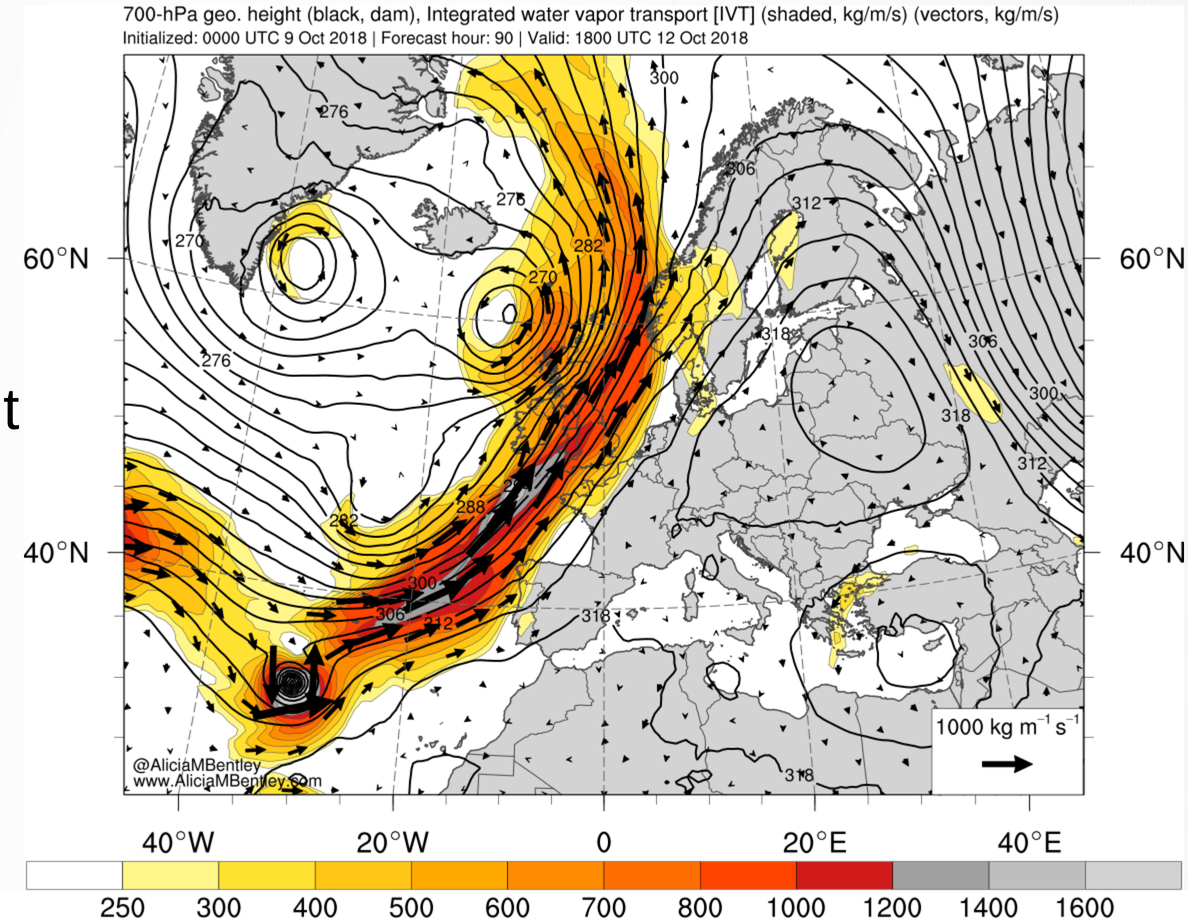
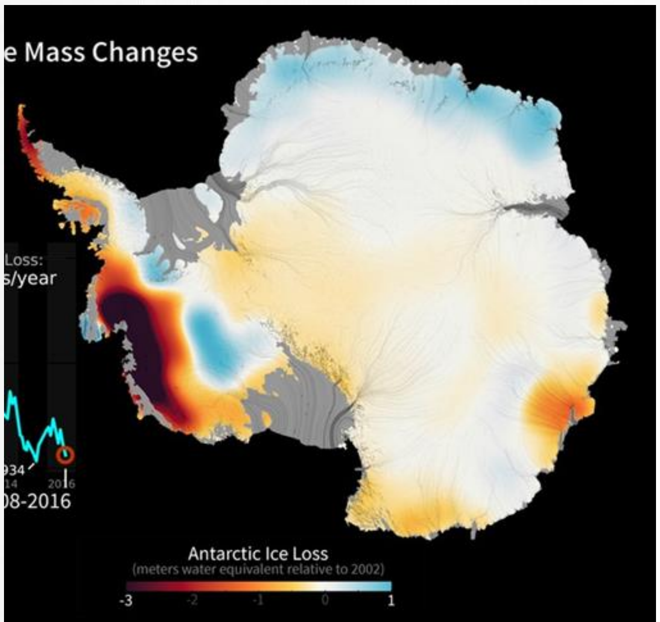
EXTRA-TROPICAL CYCLONES

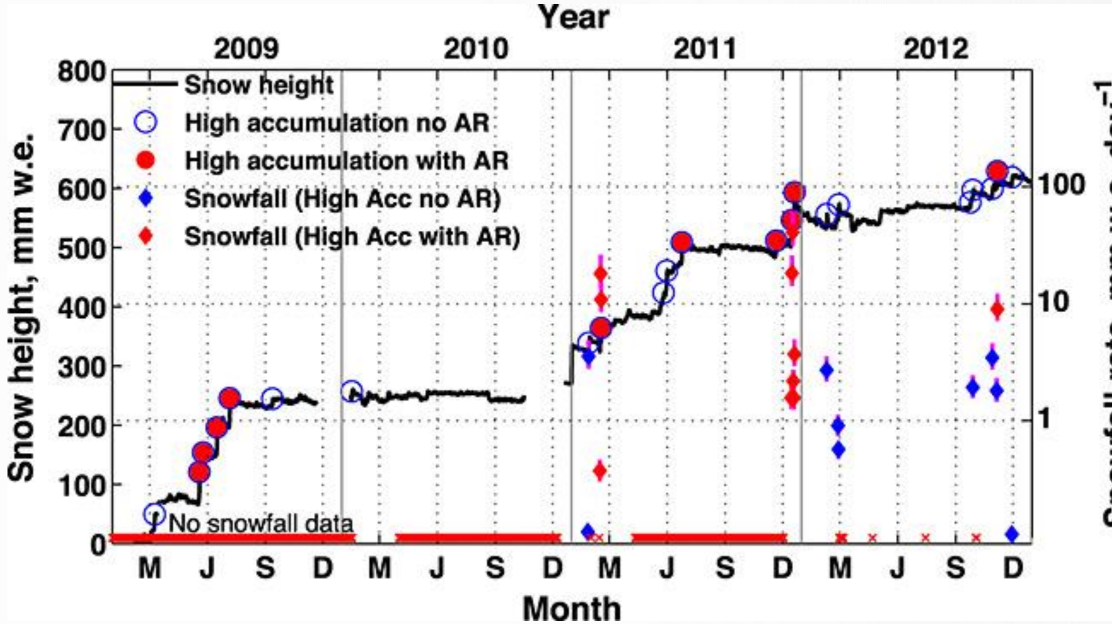
- Transport moisture from the warm, moist tropics to the midlatitudes and high latitudes
- Warm Conveyor Belt
- Atmospheric Rivers



SOUTHERN HEMISPHERE



GRACE observations. Change in mass balance relative to 2002



Snow accumulation and snow rates in East Antarctica. Relates to Atmospheric Rivers - Gorodetskaya et al (2014)

MOISTURE TRANSPORT DUE TO CYCLONES MIGHT CHANGE IF:

- The number of cyclones changes
- The location of the storm track changes
- Or the characteristics of storms change

AIM

Identify which characteristics of synoptic-scale cyclones contribute the greatest amount to meridional moisture flux *variability?*

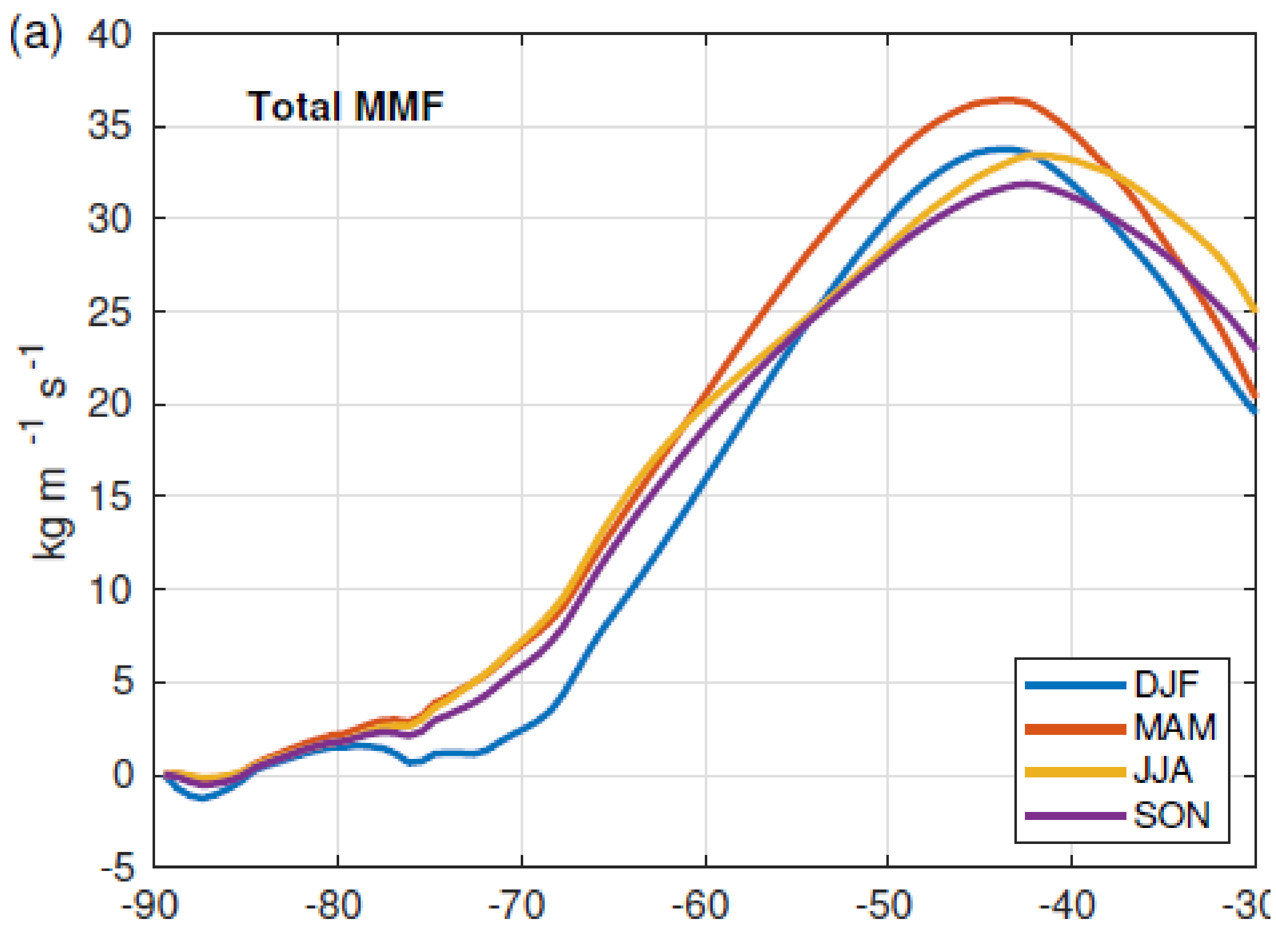
METHOD

- Use ERA-Interim reanalysis data
- 35 years (1979 – 2012), ~80 km grid spacing, 6 hour resolution
- Calculate vertically integrated meridional moisture flux between 1000 and 300 hPa
- Negative sign so that poleward MMF is positive in SH

$$\mathrm{MMF_{TOT}} = -\frac{1}{g}\int_{p1}^{p2}(vq)dp$$

CLIMATOLOGY

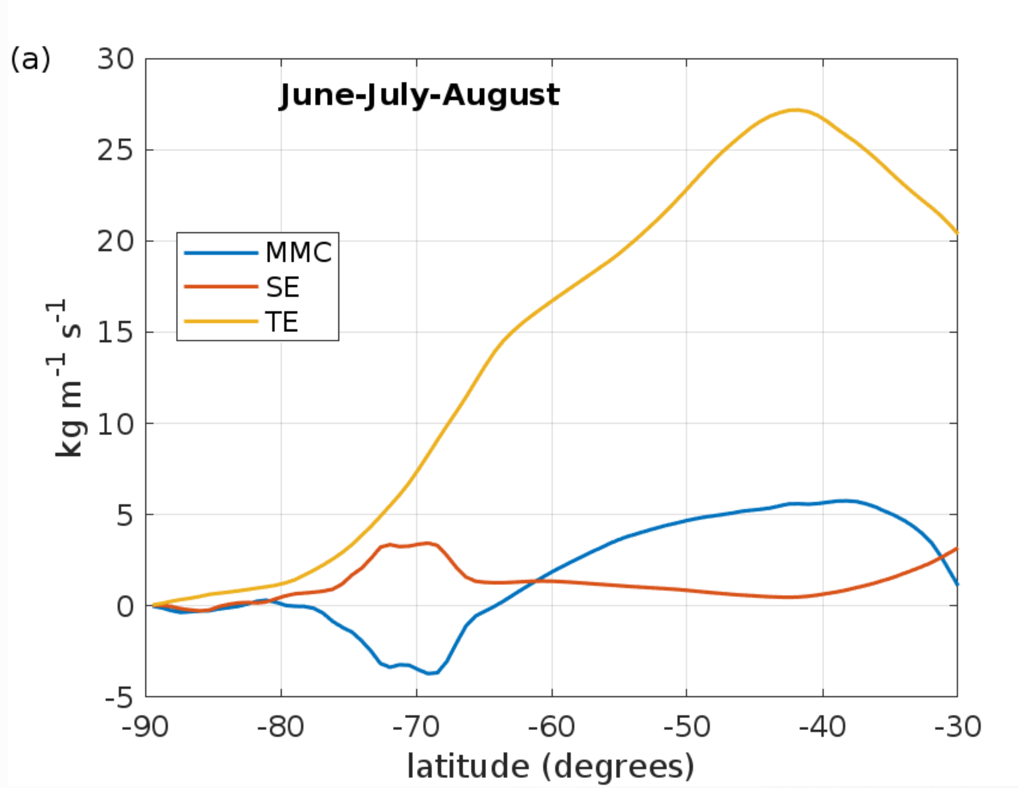
- Peak between 42S and 45S
- Largest values in SH Autumn (MAM)
- In SH summer (DJF) MMF is smaller than in all other seasons poleward of 55S



$$[\overline{qv}] = [\bar{q}][\bar{v}] + [\overline{q^* v^*}] + [\overline{q' v'}]$$

HOW TO CALCULATE MOISTURE FLUX DUE TO CYCLONES?

- Traditional approach: decompose v and q into a mean, stationary eddy and transient eddy component
- Assume transient eddies are synoptic scale systems
- Disadvantage: cannot separate cyclones with different characteristics



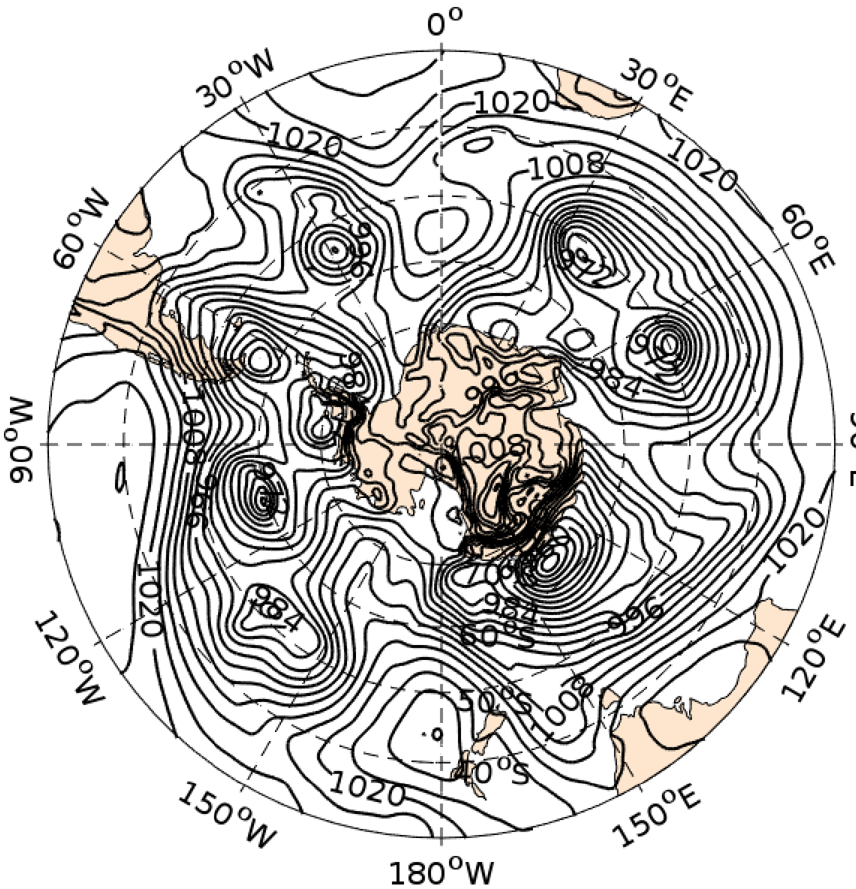
AN ALTERNATIVE METHOD

- Combine cyclone tracks with a cyclone masking method
- Similar to the method applied by Hawcroft et al (2012) for precipitation
- Track all extratropical cyclones using TRACK
  - Find localized maxima of 850-hPa relative vorticity
  - Genesis latitude, meridional speed, maximum vorticity obtained
- Create a "mask" around each cyclone centre at all times the cyclone was identified

TRACKING AND MASKING METHOD (1)

Snapshot of mean sea level pressure in the Southern Hemisphere

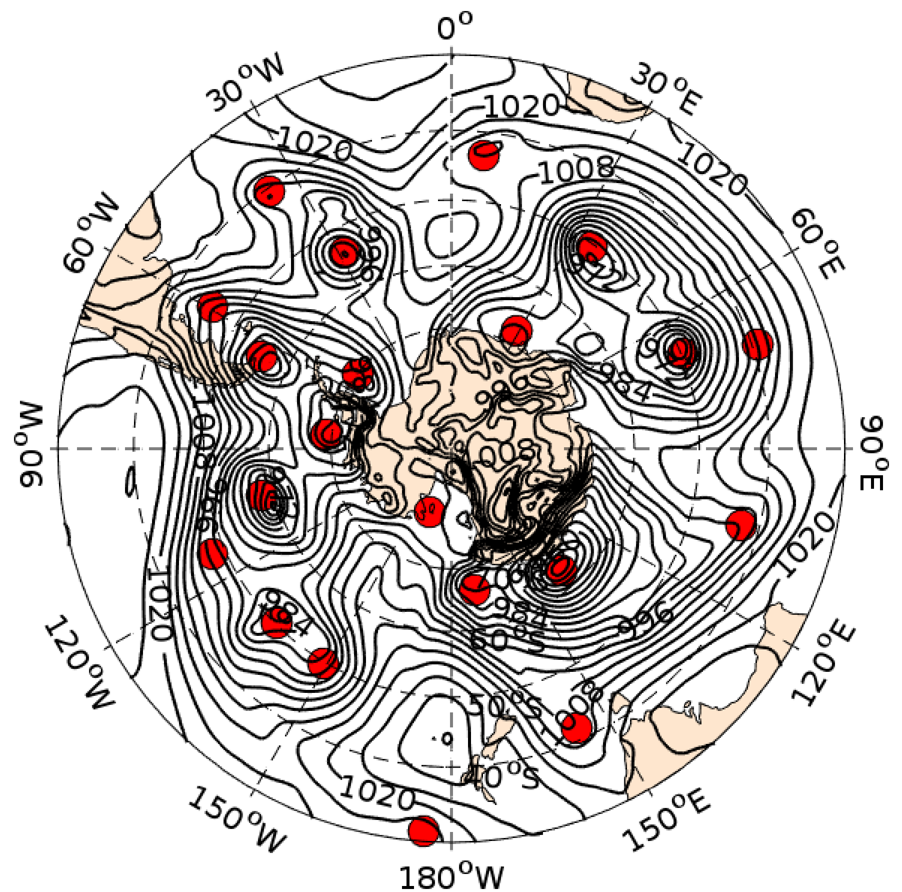
Lots of cyclones are present



TRACKING AND MASKING METHOD (2)

Red dots are the cyclone centres identified with TRACK

Not all are associated with a closed pressure contour



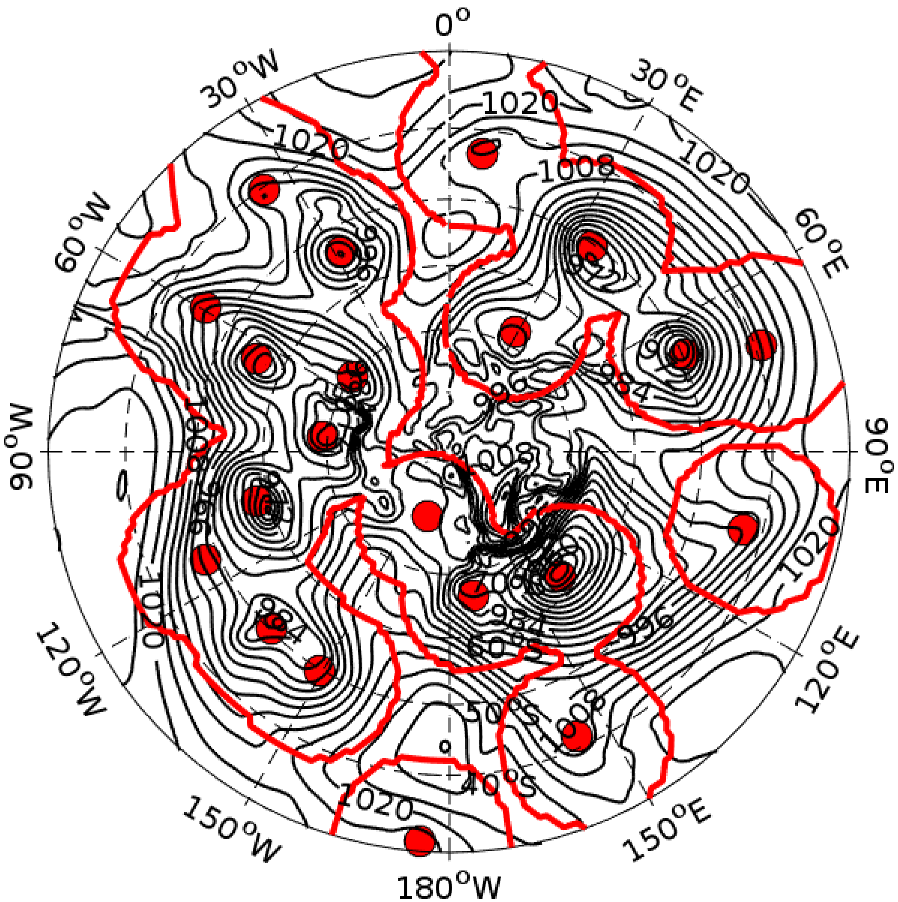
TRACKING AND MASKING METHOD (3)

Draw a mask with a radius of 12 degrees (11 degrees in DJF) around each cyclone

Moisture flux inside this mask is allocated to the cyclone

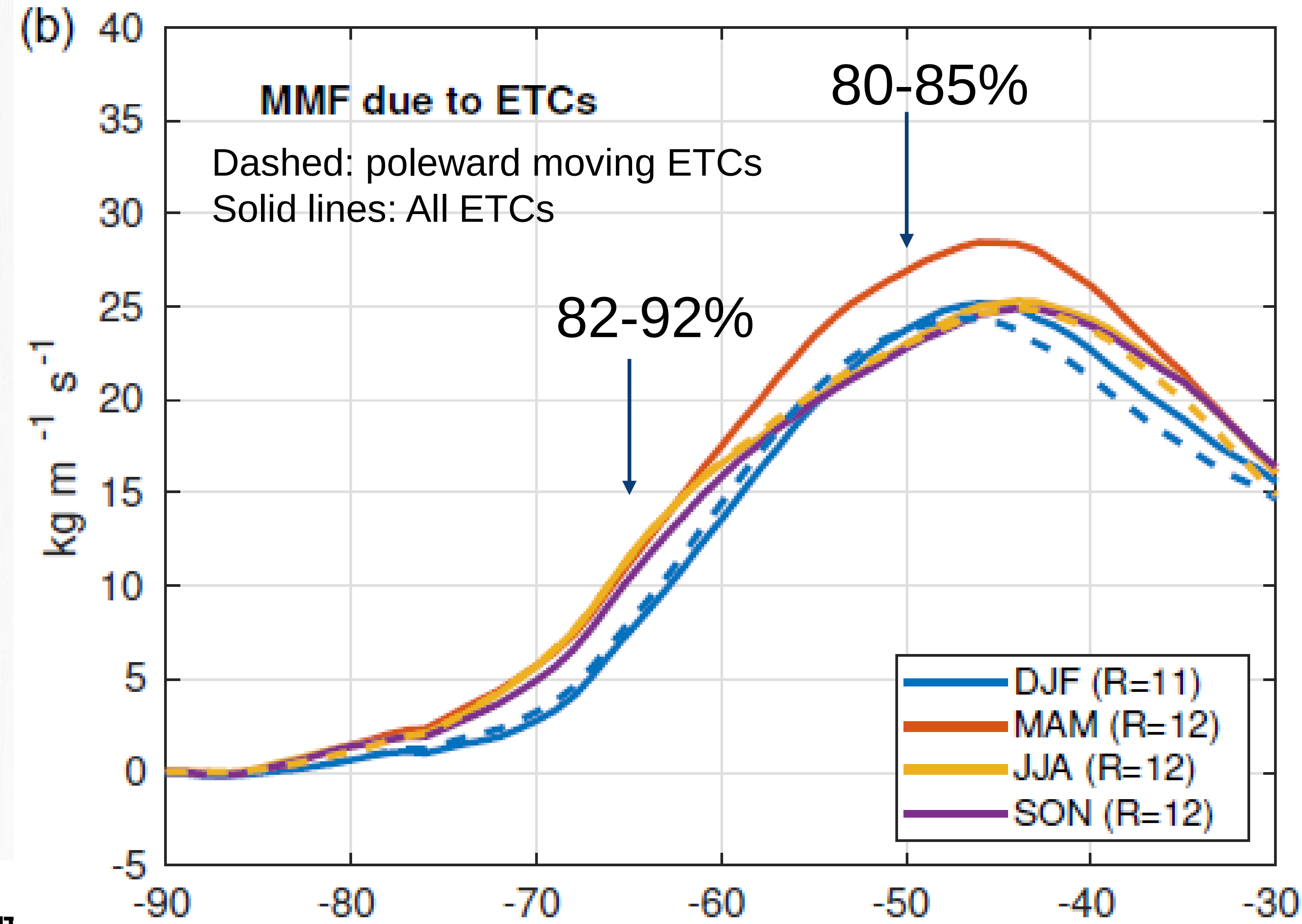
Mask=1 inside the circular cap

$$\mathrm{MMF_{ETC}} = \mathrm{MMF_{TOT}} \times mask.$$



CYCLONE MOISTURE TRANSPORT

Most meridional moisture transport is associated with extra-tropical cylones

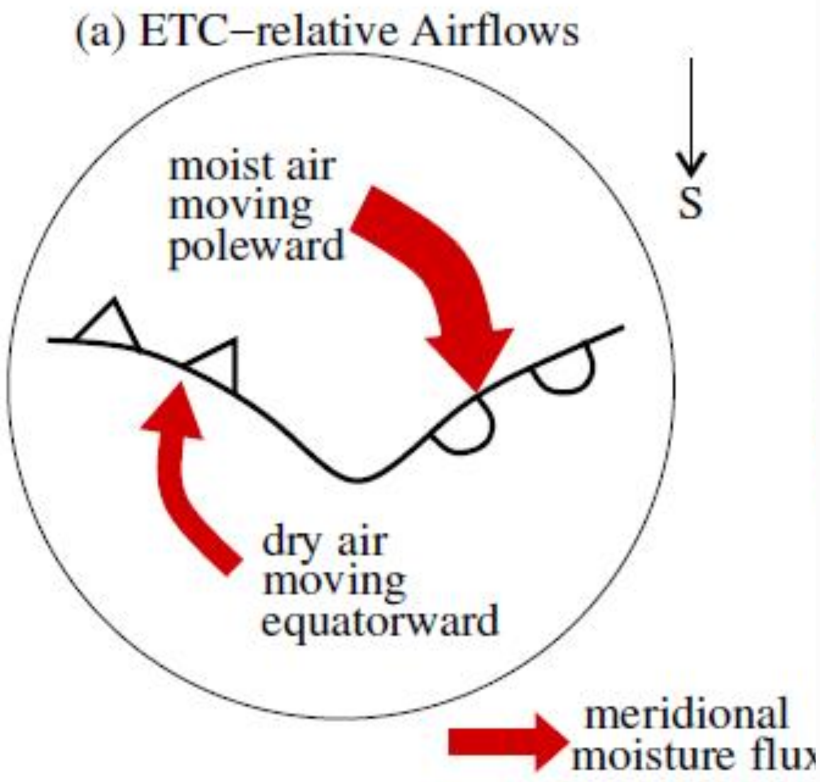


This cyclone tracking and masking method now allows us to identify the meridional moisture flux due to different types of cyclones

Consider 3 characteristics: maximum intensity, speed of meridional propagation and genesis latitude

Hypothesis 1

Maximum Vorticity



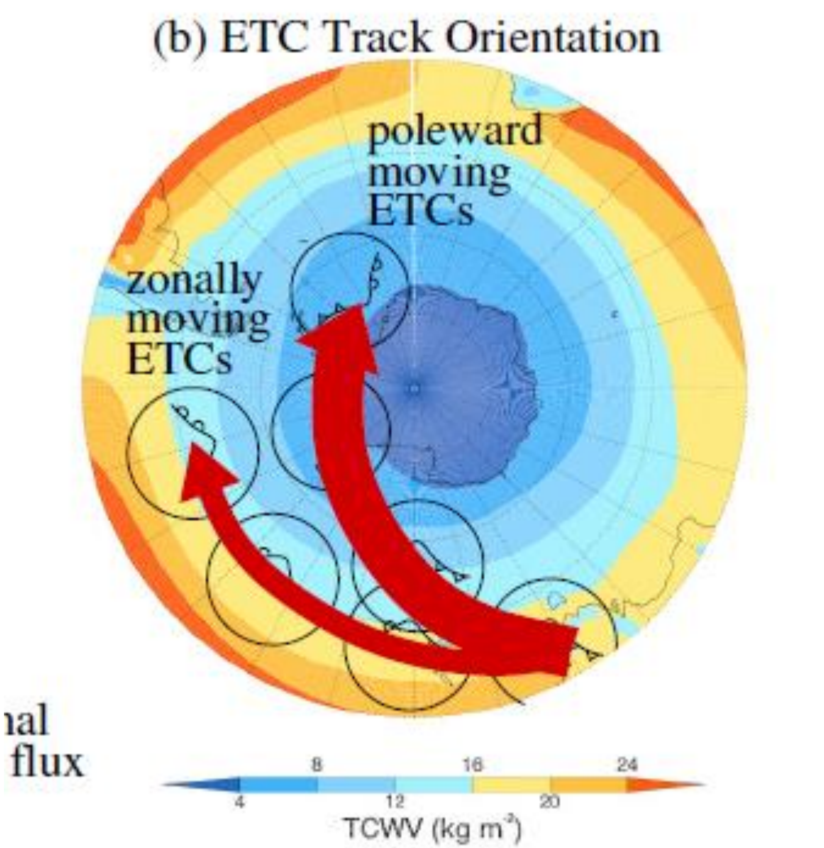
ETCs with stronger vorticity will have:

- stronger system relative air flows
- Stronger warm conveyor belt
- More meridional moisture transport

$$\mathrm{MMF}_{\mathrm{TOT}} = -\frac{1}{g}\int_{p1}^{p2}(vq)dp$$

Meridional speed = system relative winds + ETC propogation

Hypothesis 2



Propagation Speed

ETCs with more meridional tracks will have:

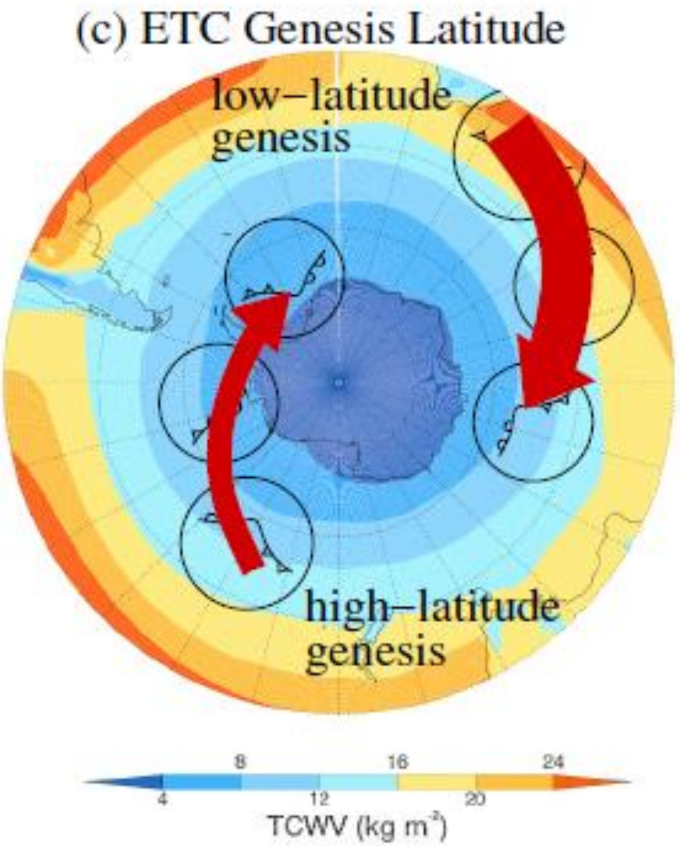
- stronger meridional propagation component
- More meridional moisture transport

$$\mathrm{MMF}_{\mathrm{TOT}} = -\frac{1}{g}\int_{p1}^{p2}(vq)dp$$

Meridional speed = system relative winds + ETC propagation

Hypothesis 3

Genesis Latitude



ETCs with more equatorward genesis regions

- Form and move through a climatological more moist region
- Will have higher values of q
- More meridional moisture transport

$$\mathrm{MMF_{TOT}} = -\frac{1}{g}\int_{p1}^{p2}(vq)dp$$

Meridional speed = system relative winds + ETC propogation

$$|MMF_{ETC}| = \frac{\sum MMF_{ETC}}{\#masks},$$

BIN CYCLONES BY CHARACTERISTICS

Bin	Max vorticity (s^{-1})	Genesis Latitude (°S)	Poleward Velocity (degrees per day)
1	$1.0 - 5.0 \times 10^{-5}$	> 67.5	$0 - 2$
2	$5.0 - 6.5 \times 10^{-5}$	$62.5 - 67.5$	$2 - 4$
3	$6.5 - 8.0 \times 10^{-5}$	55.0 - 62.5	$4 - 6$
4	$8.0 - 9.5 \times 10^{-5}$	45.0 - 55.0	$6 - 8$
5	$9.5 - 10.5 \times 10^{-5}$	$35.0 - 45.0$	$8 - 10$
6	$>10.5 \times 10^{-5}$	<35.0	>10

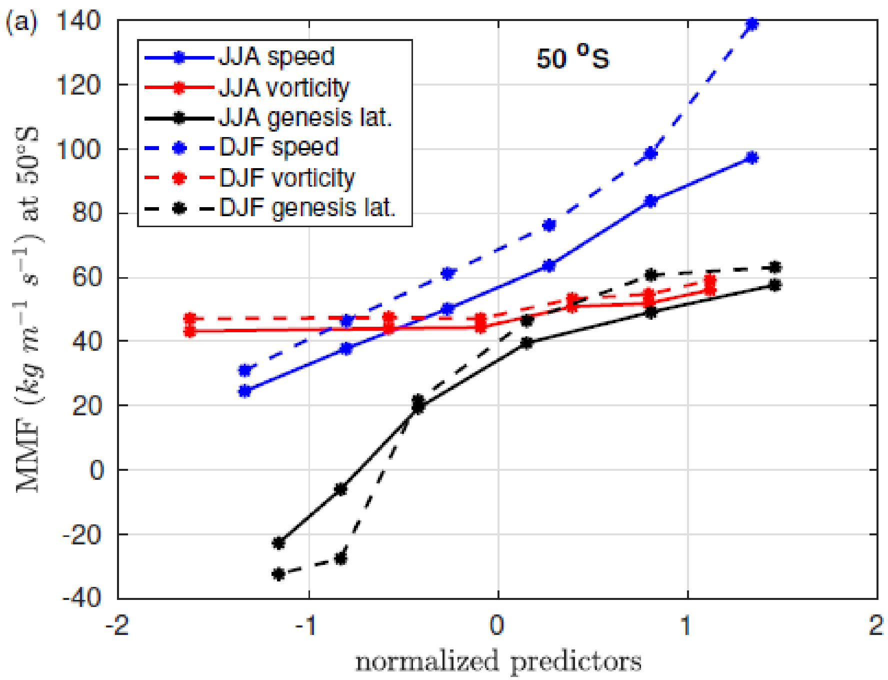
- For each 18 bins, calculate
  - an ETC mask at each time in ERA-Interim
  - The MMF associated with these ETCs
- Calculate the MMF per mask (per cyclone)
- Calculate the zonal / temporal mean

COMPARE CYCLONE CHARACTERISTICS

- Recall the aim: which cyclone characteristic leads to the *greatest variability* in the MMF
- Standardize the 3 characteristics (subtract mean, divide by standard deviation)
- Maximum vorticity, poleward propagation speed and genesis latitude

Solid lines: SH Winter
Dashed lines: SH Summer

RELATION BETWEEN CHARACTERISTICS AND MMF (50ºS)

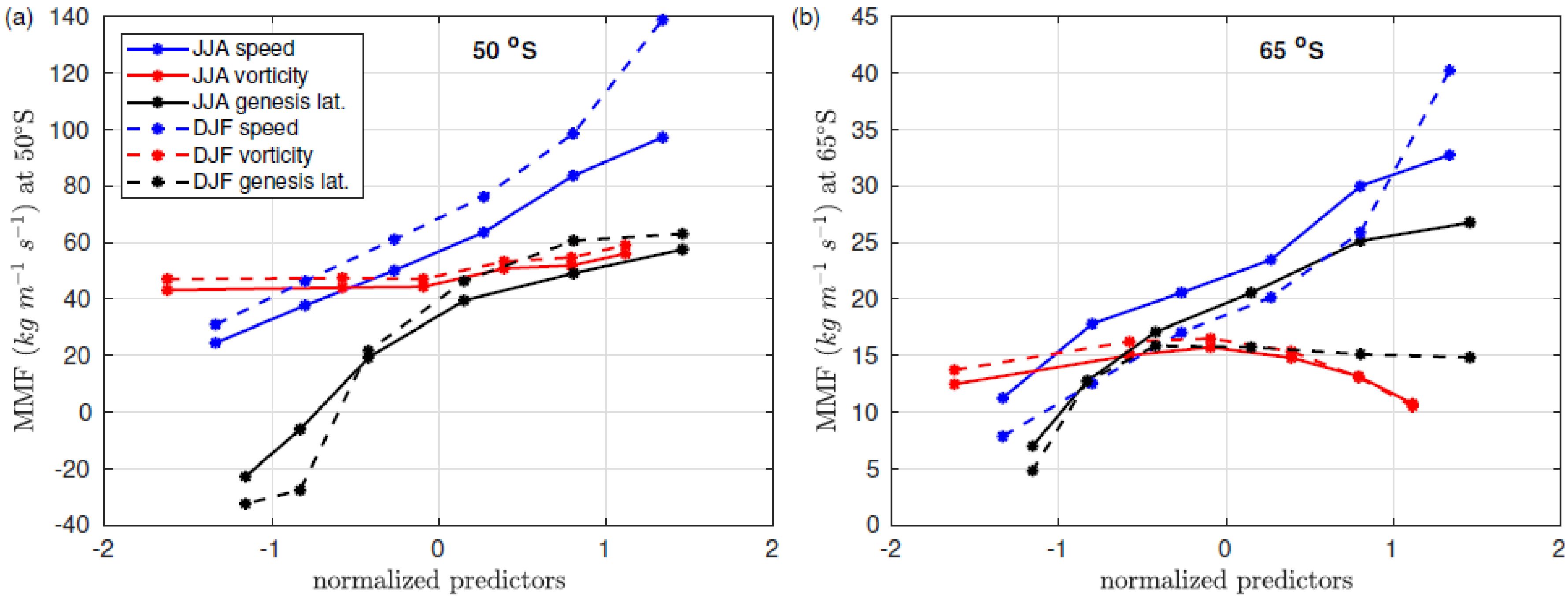


X-axis: 6 points, one per each bin.
Y-axis: the zonal mean of MMF per mask

The strongest relationship is between **genesis latitude** and MMF (closely followed by **speed**)

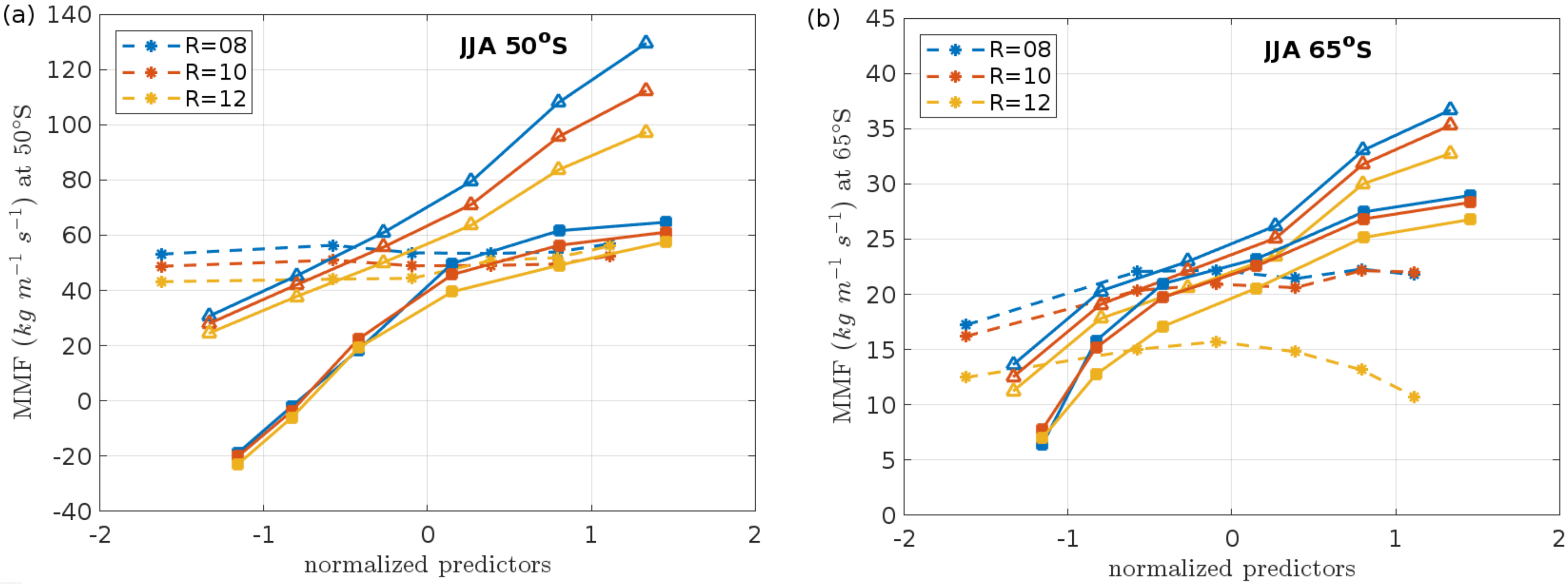
Changing the **intensity of cyclones** has a small impact on MMF

RELATION BETWEEN CHARACTERISITICS AND MMF



- At 65S, variability in the maximum vorticity has little impact on MMF
- Speed has the strongest relation with MMF at 65S

IMPACT OF CYCLONE RADIUS



The radius of the cyclone does not affect the main result

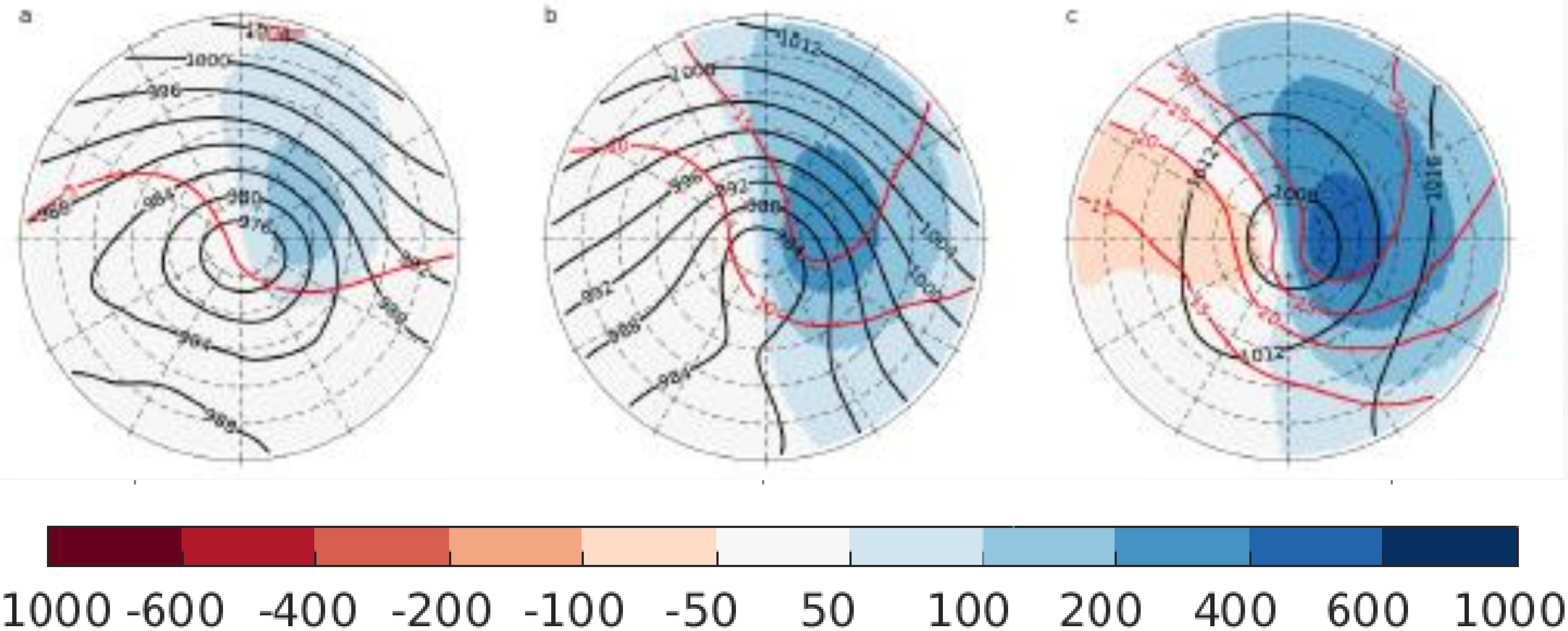
poleward propagation velocity - solid lines, triangle markers
maximum cyclonic vorticity - dashed lines, circle markers
genesis latitude - solid lines, square markers

- **Why does variability in cyclone poleward propagation speed lead to the largest variability in MMF?**
- What is the structure of the cyclones in the different bins?
- Create cyclone composites to find out
  - For each of the 18 bins, create a composite (average) of the 200 cyclones at the "top" of each bin
  - Composites are created at different stages of the cyclone lifecycle

GENESIS LATITUDE

24 hours before time of maximum vorticity

62.5 – 67.5S | 45 – 55 S | < 35S



Black contours: mean sea level pressure
Red contours: total column water vapour
Shading: meridional moisture flux

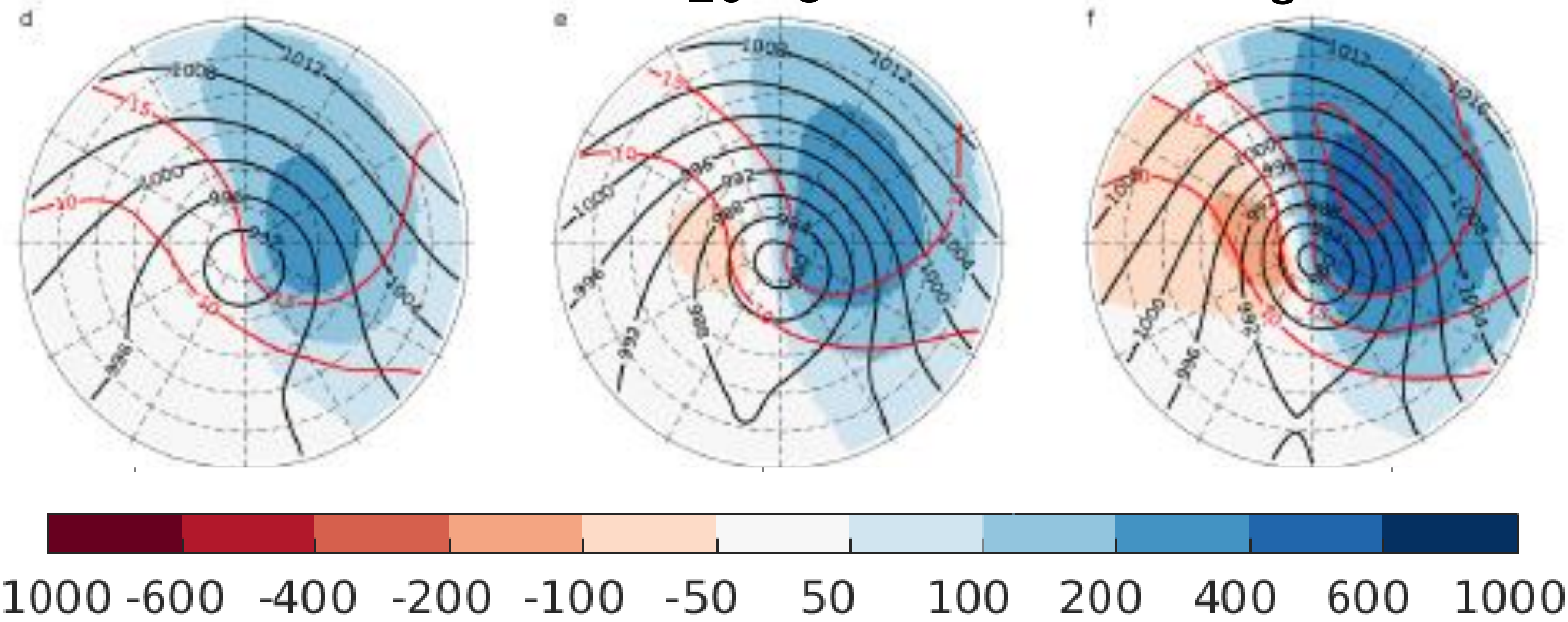
MAXIMUM VORTICITY

24 hours before time of maximum vorticity

$5 \times 10^{-5} – 6.5 \times 10^{-5}\ s^{-1}$

$8 \times 10^{-5} – 9.5 \times 10^{-5}\ s^{-1}$

$> 10.5 \times 10^{-5}\ s^{-1}$



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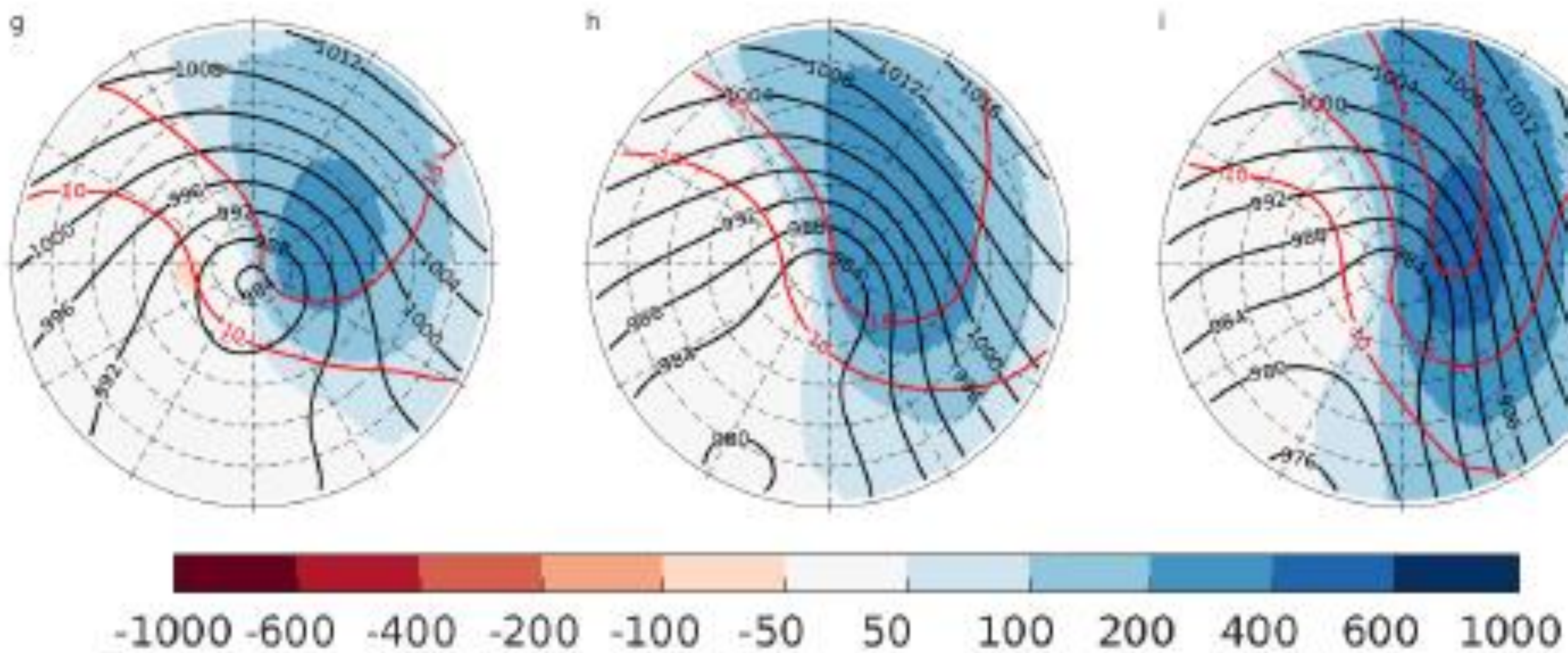
PROPAGATION SPEED

24 hours before time of maximum vorticity

2 – 4 degrees Day^{-1}	6 - 8 Degrees Day^{-1}	> 10 degrees Day^{-1}



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CONCLUSIONS

- ETC poleward propagation speed has the strongest influence on ETC meridional moisture flux particularly at high latitudes.
- Variability in ETC maximum vorticity does not impact MMF much
- Fast moving ETCs resemble a frontal wave and have no equatorward MMF.
- ETCs with lowest latitude genesis regions and highest maximum vorticities have closed low pressure center with a MMF dipole.

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